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(54) **METHODS OF FABRICATING FIN STRUCTURES OF UNIFORM HEIGHT**

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(57) **ABSTRACT**

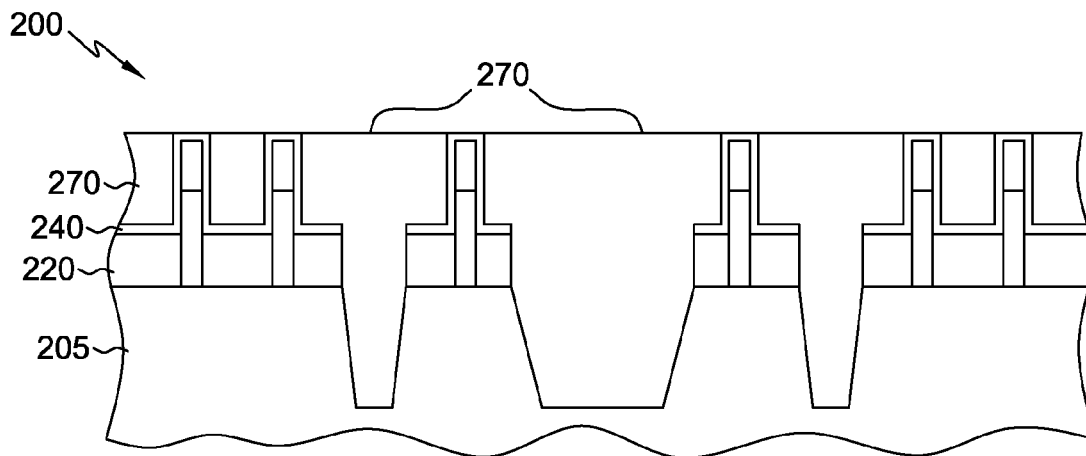
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Methods of fabricating fin structures having exposed upper fin portions with a uniform exposure height are disclosed herein. The fabrication methods include providing a substrate with plurality of fins and a dielectric material disposed between and over the plurality of fins, planarizing the dielectric material and the plurality of fins, and uniformly recessing the dielectric material to a pre-selected depth below upper surfaces of the plurality of fins to expose upper fin portions. The exposed upper fin portions, as a result of uniformly recessing the dielectric material, have a uniform exposure height above the recessed dielectric material. A protective film may be provided over the recessed dielectric material and exposed upper fin portions to preserve the uniform exposure height of the upper fin portions. The uniform exposure height of the exposed upper fin portions facilitates subsequent formation of one or more circuit structures above the substrate.

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H01L 21/8234 (2006.01)
H01L 21/3105 (2006.01)
H01L 21/306 (2006.01)
H01L 21/311 (2006.01)
H01L 29/66 (2006.01)
(52) **U.S. Cl.**
CPC .. **H01L 21/823431** (2013.01); **H01L 21/30625** (2013.01); **H01L 21/31051** (2013.01); **H01L 21/31116** (2013.01); **H01L 29/66818** (2013.01)

(58) **Field of Classification Search**
CPC H01L 29/66818
See application file for complete search history.

18 Claims, 5 Drawing Sheets



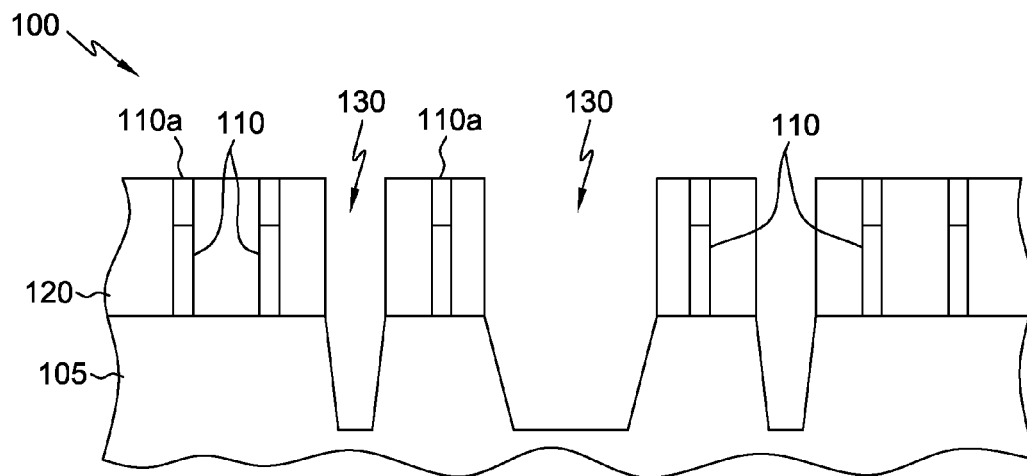


FIG. 1A

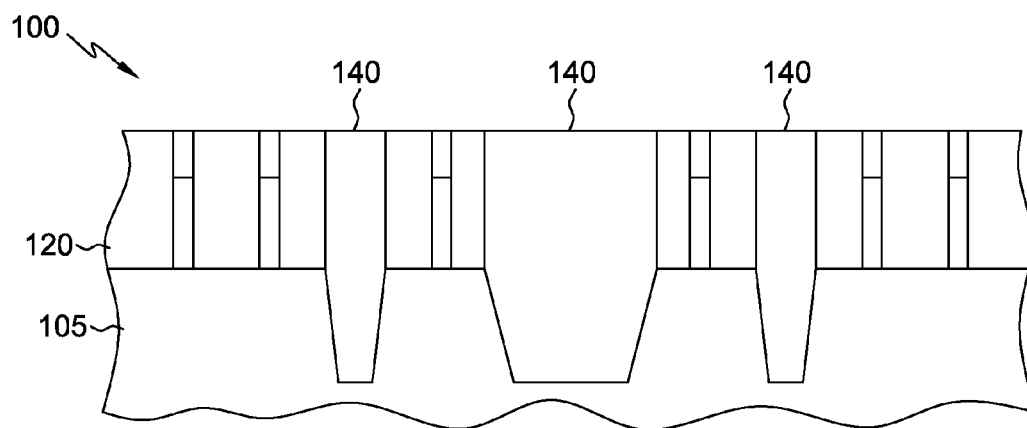


FIG. 1B

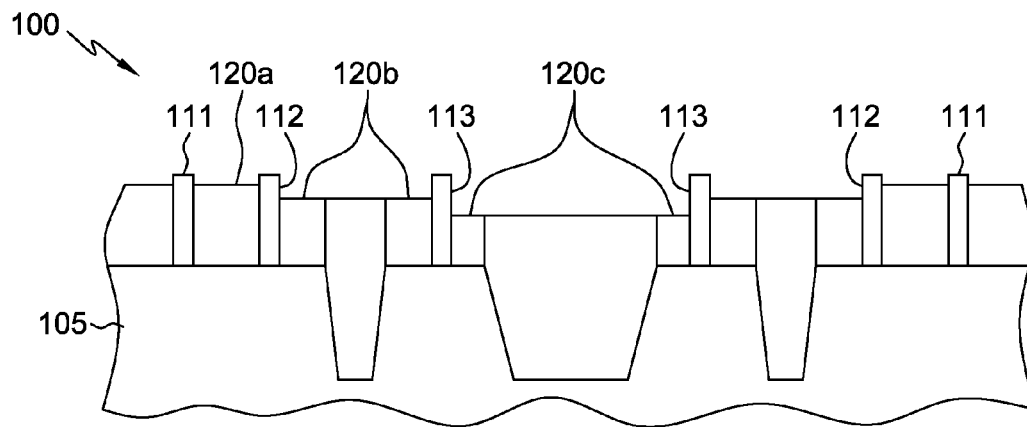


FIG. 1C

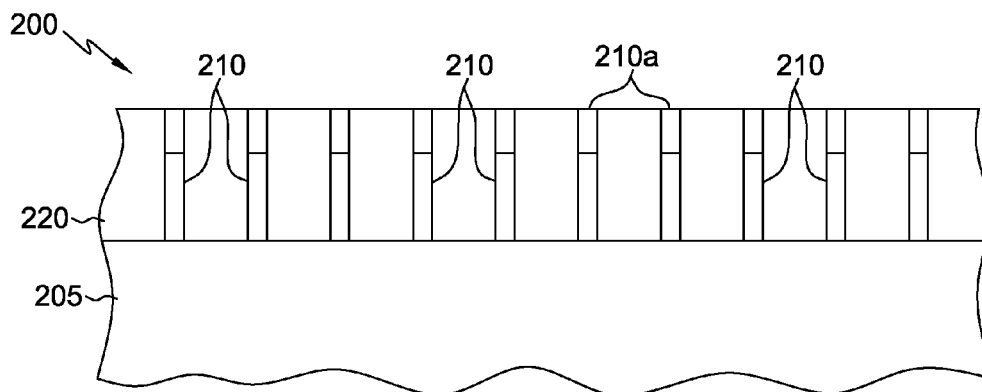


FIG. 2A

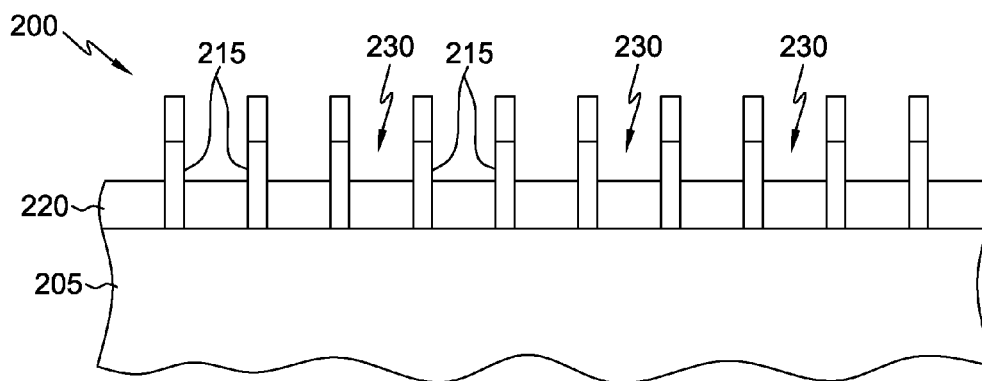


FIG. 2B

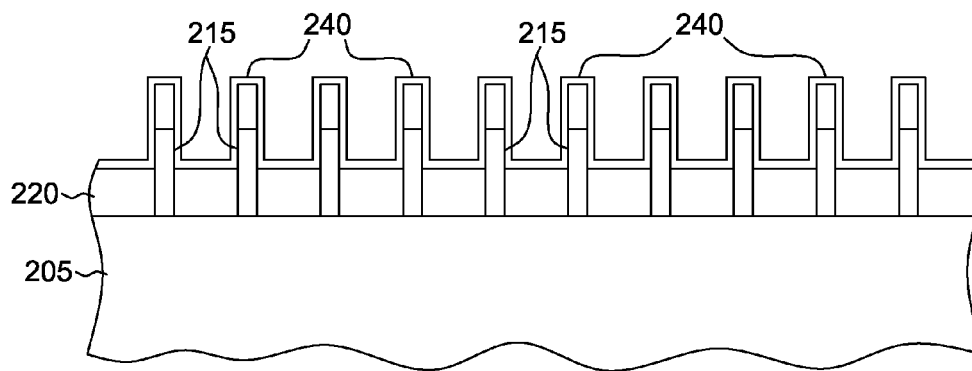


FIG. 2C

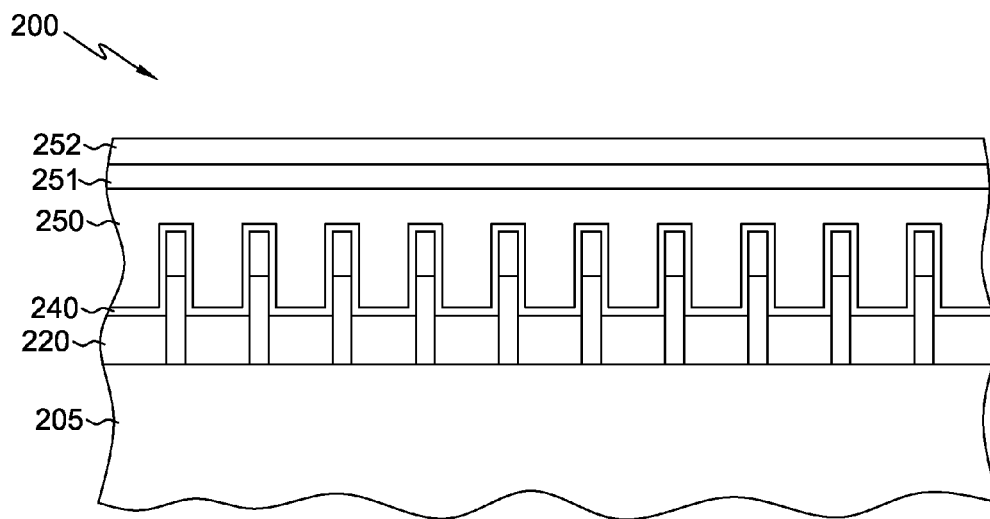


FIG. 2D

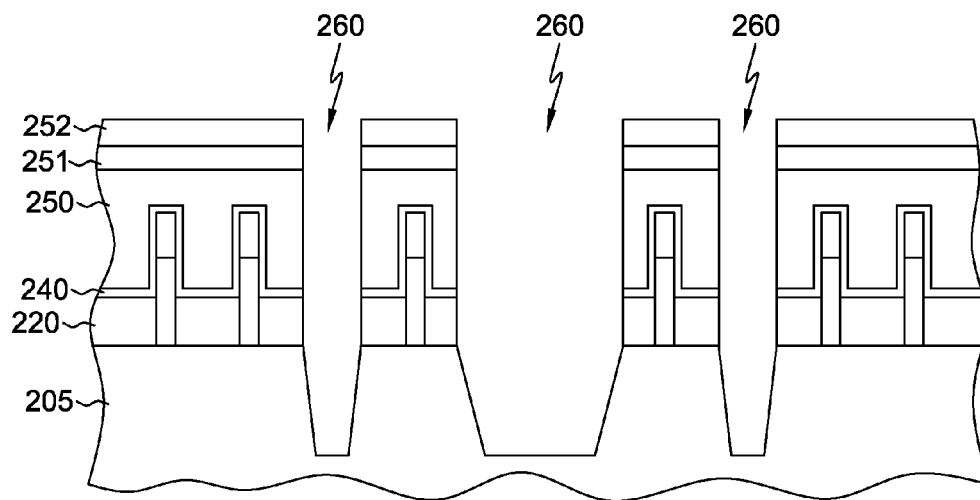


FIG. 2E

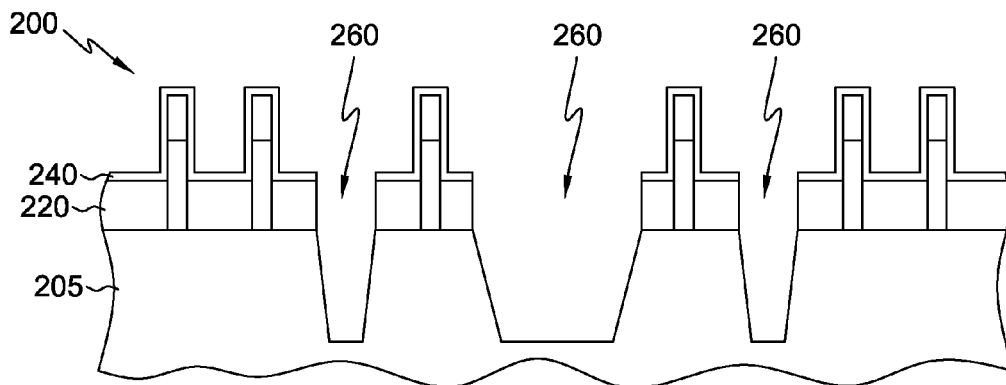


FIG. 2F

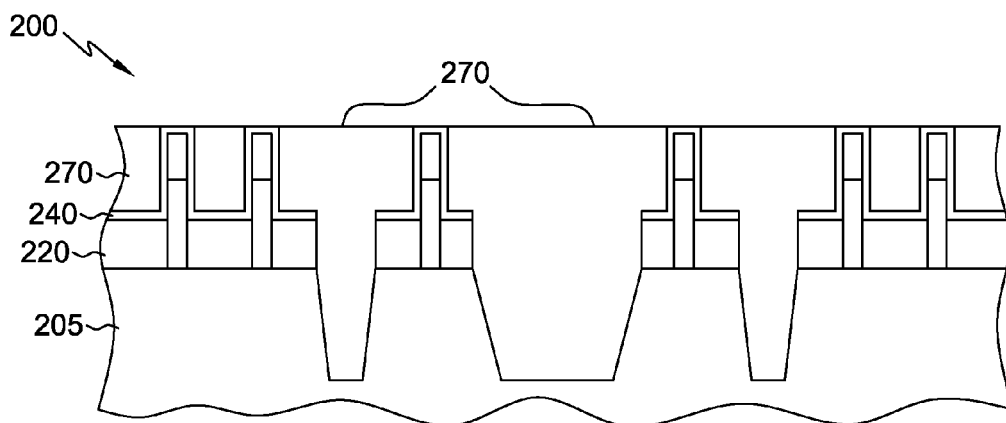


FIG. 2G

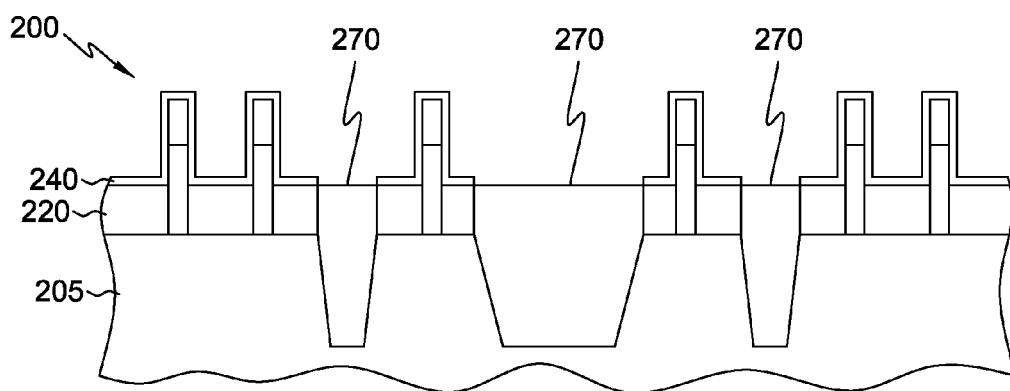


FIG. 2H

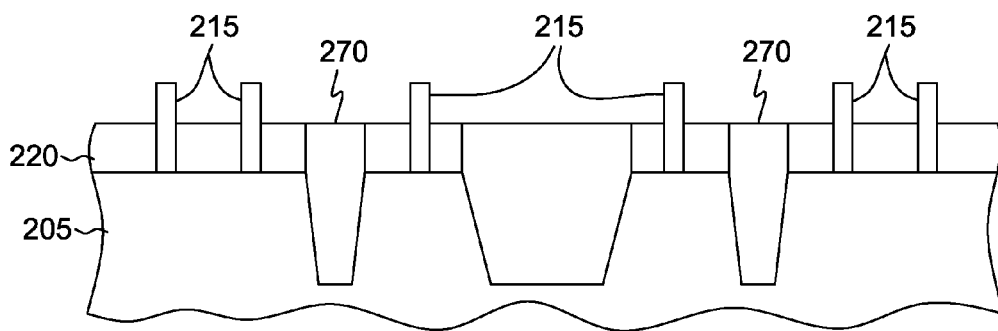


FIG. 2I

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METHODS OF FABRICATING FIN STRUCTURES OF UNIFORM HEIGHT

FIELD OF THE INVENTION

The present invention generally relates to fabricating circuit structures, and more specifically, to fin structures and methods of fabrication thereof.

BACKGROUND

Fin field-effect transistor (FinFET) devices continue to be developed to replace conventional planar metal oxide semiconductor field-effect transistors (MOSFETs) in advanced complementary metal oxide semiconductor (CMOS) technology. As is known, the term “fin” refers to a generally vertically-oriented structure within or upon which are formed, for instance, one or more FinFETs or other fin devices, such as passive devices, including capacitors, diodes, etc. Demands for smaller device sizes and challenges in fabricating FinFETs with uniform physical and electrical properties continue to drive development of new techniques of fin fabrication.

SUMMARY OF THE INVENTION

The shortcomings of the prior art are overcome and additional advantages are provided through the provision, in one aspect, of a method including: providing a substrate including a plurality of fins extending above the substrate, and a dielectric material disposed between and over the plurality of fins; planarizing the dielectric material and the plurality of fins; uniformly recessing the dielectric material to a pre-selected depth below upper surfaces of the plurality of fins to expose upper fin portions of the plurality of fins, the exposed upper fin portions of the plurality of fins having a uniform exposure height above the recessed dielectric material; and forming one or more circuit structures above the substrate using, in part, the plurality of fins, wherein the uniform exposure height of the exposed upper fin portions facilitates forming the one or more circuit structures.

Additional features and advantages are realized through the techniques of the present invention. Other embodiments and aspects are described in detail herein and are considered a part of the claimed invention.

BRIEF DESCRIPTION OF THE DRAWINGS

One or more aspects of the present invention are particularly pointed out and distinctly claimed as examples in the claims at the conclusion of the specification. The foregoing and other objects, features, and advantages of the invention are apparent from the following detailed description taken in conjunction with the accompanying drawings in which:

FIGS. 1A-1C depict one embodiment of at least part of a process for forming one or more circuit structures, illustrating problems to be addressed by processing in accordance with one or more aspects of the present invention herein; and

FIGS. 2A-2I depict one embodiment of a method of forming circuit structures using, in part, a plurality of fin structures, in which upper portions of the plurality of fin structures have a uniform height to facilitate forming the circuit structures, in accordance with one or more aspects of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

Aspects of the present invention and certain features, advantages, and details thereof, are explained more fully

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below with reference to the non-limiting examples illustrated in the accompanying drawings. Descriptions of well-known materials, fabrication tools, processing techniques, etc., are omitted so as not to unnecessarily obscure the invention in detail. It should be understood, however, that the detailed description and the specific examples, while indicating aspects of the invention, are given by way of illustration only, and are not by way of limitation. Various substitutions, modifications, additions, and/or arrangements, within the spirit and/or scope of the underlying inventive concepts will be apparent to those skilled in the art from this disclosure.

Reference is made below to the drawings, which are not drawn to scale for ease of understanding, wherein the same reference numbers used throughout different figures designate the same or similar components.

FIG. 1A depicts a cross-sectional view of a portion of one embodiment of a structure **100** at an intermediate fabrication step, illustrating conventional circuit structure fabrication methods. Structure **100** includes a substrate **105** that includes one or more fins **110** above the substrate and a first dielectric material **120** disposed between or around the one or more fins **110**. Fins **110** may, in general, be formed by applying a patterned mask **110a**, such as a patterned silicon nitride hard mask, over a bulk semiconductor substrate, such as a silicon wafer, and etching fins **110**. Following fin etching, a first dielectric material **120** may be disposed between fins **110** to, in part, electrically isolate fins **110** from each other. Fabrication techniques for many circuit structures, such as SRAM unit cells, include a “fin cutting” step to remove portions of certain fins, or entirely removing other fins, to form trenches **130** in substrate **105**. As discussed below, trenches **130** are formed to form, in part, isolation trenches between fins within a single circuit structure, and/or between two or more separate circuit structures on the same substrate **105**.

FIG. 1B depicts structure **100** following disposal of a second dielectric material **140** in the trenches **130** of FIG. 1A. Second dielectric material **140** is disposed in the trenches to form isolation trenches that electrically isolate separate circuit structures, such as two adjacent transistors formed in the same substrate, or that electrically isolate features within a single circuit structure, such as a p-type FinFET and an n-type FinFET within a single transistor. Second dielectric material **140** may be the same material as first dielectric material **120**. Although first and second dielectric materials **120** and **140** need not be identical materials, the first and second dielectric materials are generally both susceptible to the same recessing technique so that both may be recessed in a single step, as illustrated by FIG. 1C and described below. Generally both first dielectric material **120** and second dielectric material **140** are different type of materials from the material of patterned mask **110a**, so that fabrication steps that may affect first and second dielectric materials **120** and **140**, such as recessing first and second dielectric materials, do not affect patterned mask **110a** and vice versa.

FIG. 1C depicts structure **100** following exposure of upper fin portions **111**, **112**, **113** of the fins via recession of first dielectric material **120** and second dielectric material **140**, as well as removal of remaining patterned mask **110a**. Recession of first and second dielectric materials **120**, **140** may be accomplished, for example, by etching first and second dielectric materials **120**, **140** at an etch rate that depends on a spacing or “pitch” between fins. For example, common dry etching techniques may recess dielectric material **120** at a slower rate between two fins separated by a relatively small pitch, such as between fins **111** and **112** in FIG. 1C, while the same dry etching process may recess first and second dielectric materials **120**, **140** more rapidly between two fins separated by a larger pitch, such as between fins **112** and **113** in FIG. 1C.

rated by a relatively large pitch, as between fins **112** and **113**. Thus, the same recessing process may result in unequal recession of first dielectric material **120a**, **120b**, **120c** between different pairs of fins, further resulting in upper fin portions **111**, **112**, and **113** having unequal heights above the first dielectric material.

In subsequent processing steps, a gate material may be formed over upper fin portions **111**, **112**, **113** to form FinFET structures, defining, in part, one or more circuit structures. As the gate material generally only contacts the exposed upper fin portions of the one or more fins, the physical sizes of exposed upper fin portions **111**, **112**, **113** define the channel sizes of the formed FinFET structures. Consequently, the uneven sizes of upper fin portions **111**, **112**, **113** result in FinFET structures with different physical and electrical properties. In particular the FinFET structures may have variable channel sizes of the FinFET structures and, consequently, variable threshold voltages for operation of the FinFETs within a single circuit structure and among separate circuit structures, resulting in circuit structures with sub-optimal or undesirably variable performance. Thus, there is a need for novel methods for fabricating fins having exposed upper fin portions with uniform exposure heights. Ideally, fins having uniform exposure heights may be achieved using existing fabrication tools and materials to reduce fabrication costs associated with newer tools.

Generally stated, provided herein in one aspect is a method including: providing a substrate including a plurality of fins extending above the substrate, and a dielectric material disposed between and over the plurality of fins; planarizing the dielectric material with the plurality of fins; uniformly recessing the dielectric material to a pre-selected depth below upper surfaces of the plurality of fins to expose upper fin portions of the plurality of fins, the exposed upper fin portions of the plurality of fins having a uniform exposure height above the recessed dielectric material; and forming one or more circuit structures above the substrate using, in part, the plurality of fins, wherein the uniform exposure height of the exposed upper fin portions facilitates forming the one or more circuit structures.

FIGS. 2A-2I depict one embodiment of such an approach to, in part, achieve a uniform exposure height of upper fin portions, in accordance with one or more aspects of the present invention.

FIG. 2A depicts a cross-section of at least a portion of one embodiment of a structure **200** including a substrate **205**, a plurality of fins **210** formed above substrate **205**, and a dielectric material **220** disposed between the plurality of fins **210**. The plurality of fins **210** may be formed, for example, by providing a patterned mask **210a**, such as a patterned hard mask, over a semiconductor substrate **205** and using the patterned mask **210a** to etch the plurality of fins **210** in the substrate **205**. Patterned mask **210a** may, in one example, be a patterned silicon nitride hard mask. Forming the plurality of fins **210** may result in the plurality of fins **210** having a uniform fin height above substrate **205**. The plurality of fins **210** may, in one example, be planarized prior to providing dielectric material **220** between plurality of fins **210** and prior to planarizing dielectric material **220** in order to achieve a uniform fin height of the plurality of fins **210**. Forming the plurality of fins may also result in the plurality of fins **210** having a uniform pitch size separating the plurality of fins **210**. Dielectric material **220** may, in one example, be an oxide material such as silicon dioxide. Dielectric material **220** may, at least initially, be disposed between and over the plurality of fins **210**, and may subsequently be planarized along with the plurality of fins **210**, as illustrated in FIG. 2A. Planarizing

dielectric material **220** may include, for example, a chemical-mechanical polishing (CMP) terminating when the dielectric is co-planar with upper surfaces of the plurality of fins **210**. For example, the upper surfaces of the plurality of fins **210** may include patterned mask **210a**, and the chemical-mechanical polishing may terminate when dielectric material **220** is coplanar with the patterned mask **210a**.

FIG. 2B depicts the structure **200** of FIG. 2A following uniformly recessing the dielectric material **220** to a pre-selected depth **230** below upper surfaces of the plurality of fins **210** (FIG. 2A) to expose upper fin portions **215** of the plurality of fins **210**. The exposed upper fin portions **215** have a uniform exposure height above the recessed dielectric material **220**. Uniformly recessing the dielectric material **220** may include, for example, recessing the dielectric material at a uniform recession rate that is dependent, in part, on a pitch size separating the plurality of fins **210**. For example, uniformly recessing dielectric material **220** may include a reactive-ion etching (RIE) of dielectric material **220**. If, as in the exemplary embodiment depicted in FIGS. 2A-2B, the pitch size of the plurality of fins **210** is a uniform pitch size, the uniform pitch size may facilitate uniformly recessing dielectric material **220** at the uniform recession rate. Thus, by recessing dielectric material **220** when the pitch separating plurality of fins **210** is a uniform pitch size, exposed upper fin portions **215** may have a uniform exposure height above recessed dielectric material **220**. As well, in exemplary embodiments the plurality of fins **210** of FIG. 2A have a uniform fin height above substrate **205**, so that the uniform fin height facilitates forming upper fin portions **215** to a uniform exposure height.

FIG. 2C depicts the structure **200** of FIG. 2B with a protective film **240** provided over exposed upper fin portions **215** and recessed dielectric material **220**. Protective film **240** may be provided in exemplary embodiments to protect recessed dielectric material **220** and upper fin portions **215** during subsequent processing steps, as described herein below. As a uniform exposure height of upper fin portions **215** is achieved through uniformly recessing dielectric material **220**, protective film **240** facilitates preserving the uniform exposure height in the subsequent forming of one or more circuit structures.

FIGS. 2D-2E depict the structure **200** of FIG. 2C undergoing removal of at least a portion of one or more of the plurality of fins **210** to form one or more trenches in substrate **205**. Removal of at least a portion of one or more of the plurality of fins **210** may, in at least one embodiment, include etching through at least a portion of one or more of the plurality of fins and a portion of the substrate. In exemplary embodiments including protective film **240**, the etching also removes a portion of the protective film **240** over the at least a portion of the one or more of the plurality of fins **210**. The etching may include, for example, lithographic etching of the fin portion and the portion of the substrate as illustrated in FIGS. 2D-2E. Lithographic etching may begin, as in FIG. 2D, by deposition of an organic material layer **250**, an anti-reflective coating layer **251**, and photo-resist layer **252** over the plurality of fins **210** and dielectric material **220**, as well as protective film **240**. Photo-resist layer **252** may be patterned to expose portions of the underlying layers, and the exposed portions may be etched by irradiation to form trenches **260**, as depicted in FIG. 2E. Protective film **240**, as well as dielectric material **220** and substrate **205**, ideally are made of materials susceptible to lithographic etching. Portions of protective film **240** thus may also be removed by etching, and protective film **240** does not

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prevent the removal of at least a portion of one or more of the plurality of fins **210** and formation of one or more trenches **260**.

FIG. 2F depicts the structure **200** of FIG. 2E following formation of trenches **260** and removal of layers **250**, **251**, **252** from over protective film **240**. Removal of layers **250**, **251**, **252** may be accomplished by any method that removes an organic layer **250**, anti-reflective coating layer **251**, and photo-resist layer **252** without etching or affecting protective layer **240**, dielectric layer **220** and substrate **205**.

FIG. 2G depicts the structure **200** of FIG. 2F following deposition of a second dielectric material **270**. In exemplary embodiments, dielectric material **220** may be a first dielectric material, and a second dielectric material **270** may be provided to fill the one or more trenches **260** (FIG. 2F) to form isolation trenches of and/or between one or more circuit structures formed above substrate **205**. Second dielectric material **270** and first dielectric material **220** may be the same type of material, such as an oxide material. In one example, providing second dielectric material **270** may include planarizing the second dielectric material **270** with an upper surface of the protective film **240** over the plurality of fins **210**. For instance, second dielectric material **270** may be planarized by chemical-mechanical polishing that terminates when second dielectric material **240** is co-planar with the upper surface of protective film **240**.

FIG. 2H depicts structure **200** of FIG. 2G following recessing second dielectric material **270**, in which the recessing does not further recess first dielectric material **220**. The recess depth of second dielectric material can be deeper, so that top level of second dielectric material can be lower than that of first dielectric material. In exemplary embodiments including protective film **240**, second dielectric material **270** and protective film **240** are different materials such that protective film **240** is not susceptible to recessing of second dielectric material **270**, so that first dielectric material **220** beneath protective film **240** is protected from the recessing of the second dielectric material **270**. For example, protective film **240** may be a nitride material, such as silicon nitride, and second dielectric material **270** may be an oxide material, such as silicon dioxide. Recessing techniques that affect oxide materials, such as a reactive-ion etch (RIE) process configured to etch oxide materials, generally do not similarly affect or etch nitride materials and vice versa, thus protective film **240** preserves first dielectric material **220** and upper fin portions of the plurality of fins **210** during recessing of second dielectric material **270**. In exemplary embodiments, second dielectric material **270** may be recessed to a depth below protective film **240**, as illustrated in FIG. 2H, and second dielectric material **270** may be further recessed below upper surfaces of first dielectric material **220**.

FIG. 2I depicts structure **200** of FIG. 2H following removal of protective film **240**, as well as patterned mask **210a** (FIG. 2A) if present, after recession of the second dielectric material, exposing upper fin portions **215** of the plurality of fins. Upper fin portions **215**, as illustrated in FIG. 2I, have a uniform exposure height above the recessed first dielectric material **210**. In subsequent circuit structure fabrication steps, a plurality of gate structures (not depicted in FIG. 2I) may be provided over the exposed upper fin portions **215** to facilitate forming a plurality of FinFET structures. Generally in any single FinFET structure of a circuit structure, an exposed upper fin portion of a fin defines the channel size of the FinFET; the remaining portion of the fin within the dielectric material may not affect the FinFET channel size. As depicted in the exemplary embodiment of FIG. 2I, the uniform exposure height of upper fin portions **215** defines a uniform chan-

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nel size for the plurality of FinFET structures formed, at least in part, by provision of a plurality of gate structures over the exposed fin portions. Thus, the exemplary embodiment of the fin formation approach depicted in FIGS. 2A-2I may achieve a uniform channel size for FinFET structures, as may be desired for many types of circuit structures. For example, in many circuit structures it is desirable for the gate structures of multiple FinFET structures to have a uniform threshold voltage for operation of the circuit structure. Such a uniform threshold voltage may be ideally achieved by ensuring a uniform channel size, defined by the upper fin portions, beneath the gate structures.

Approximating language, as used herein throughout the specification and claims, may be applied to modify any quantitative representation that could permissibly vary without resulting in a change in the basic function to which it is related. Accordingly, a value modified by a term or terms, such as "about," is not limited to the precise value specified. In some instances, the approximating language may correspond to the precision of an instrument for measuring the value.

The terminology used herein is for the purpose of describing particular examples only and is not intended to be limiting of the invention. As used herein, the singular forms "a," "an" and "the" are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms "comprise" (and any form of comprise, such as "comprises" and "comprising"), "have" (and any form of have, such as "has" and "having"), "include" (and any form of include, such as "includes" and "including"), and "contain" (and any form of contain, such as "contains" and "containing") are open-ended linking verbs. As a result, a method or device that "comprises," "has," "includes" or "contains" one or more steps or elements possesses those one or more steps or elements, but is not limited to possessing only those one or more steps or elements. Likewise, a step of a method or an element of a device that "comprises," "has," "includes" or "contains" one or more features possesses those one or more features, but is not limited to possessing only those one or more features.

As used herein, the terms "may" and "may be" indicate a possibility of an occurrence within a set of circumstances; a possession of a specified property, characteristic or function; and/or qualify another verb by expressing one or more of an ability, capability, or possibility associated with the qualified verb. Accordingly, usage of "may" and "may be" indicates that a modified term is apparently appropriate, capable, or suitable for an indicated capacity, function, or usage, while taking into account that in some circumstances the modified term may sometimes not be appropriate, capable or suitable. For example, in some circumstances, an event or capacity can be expected, while in other circumstances the event or capacity cannot occur—this distinction is captured by the terms "may" and "may be."

While several aspects of the present invention have been described and depicted herein, alternative aspects may be effected by those skilled in the art to accomplish the same objectives. Accordingly, it is intended by the appended claims to cover all such alternative aspects as fall within the true spirit and scope of the invention.

What is claimed is:

1. A method comprising:

providing a substrate comprising a plurality of fins extending above the substrate, and a dielectric material disposed between and over the plurality of fins, the plurality of fins being planarized to have a uniform fin height above the substrate;

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thereafter, planarizing the dielectric material;
uniformly recessing the dielectric material to a pre-selected depth below upper surfaces of the plurality of fins to expose upper fin portions of the plurality of fins, the exposed upper fin portions of the plurality of fins having a uniform exposure height above the recessed dielectric material, wherein the uniform fin height facilitates the uniformly recessing; and

forming one or more circuit structures above the substrate using, in part, the plurality of fins, wherein the uniform exposure height of the exposed upper fin portions facilitates forming the one or more circuit structures.

2. The method of claim 1, wherein uniformly recessing the dielectric material comprises recessing the dielectric material at a uniform recession rate, the uniform recession rate being dependent, in part, on a pitch size separating the plurality of fins.

3. The method of claim 2, wherein the pitch size is a uniform pitch size, the uniform pitch size facilitating uniformly recessing the dielectric material at the uniform recession rate.

4. The method of claim 1, wherein planarizing the dielectric material comprises a chemical-mechanical polishing terminating when the dielectric material is co-planar with the upper surfaces of the plurality of fins.

5. The method of claim 1, further comprising providing a plurality of gate structures over the exposed upper fin portions of the plurality of fins to facilitate forming a plurality of FinFET structures, wherein a uniform channel size of the plurality of FinFET structures is defined by the uniform exposure height of the upper fin portions of the plurality of fins.

6. The method of claim 1, further comprising removing at least a portion of one or more of the plurality of fins following uniformly recessing the dielectric material, the removing forming one or more trenches in the substrate.

7. The method of claim 6, wherein the removing comprises etching through at least a portion of one or more of the plurality of fins and a portion of the substrate to form the one or more trenches.

8. The method of claim 6, wherein the dielectric material is a first dielectric material, the method further comprising providing a second dielectric material, the second dielectric

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material filling the one or more trenches to form one or more isolation trenches of the one or more circuit structures.

9. The method of claim 8, further comprising recessing the second dielectric material, wherein the recessing does not further recess the first dielectric material.

10. The method of claim 9, further comprising providing a protective film over the exposed upper fin portions of the plurality of fins and the first dielectric material prior to providing the second dielectric material, wherein the protective film protects the first dielectric material during the recessing of the second dielectric material.

11. The method of claim 10, wherein the second dielectric material comprises an oxide material and the protective film comprises a nitride material resistant to the recessing of the second dielectric material.

12. The method of claim 10, wherein the removing at least a portion of one or more of the plurality of fins further comprises removing a portion of the protective film over the at least a portion of the one or more of the plurality of fins.

13. The method of claim 10, wherein recessing the second dielectric material comprises recessing the second dielectric material to a depth below the protective film.

14. The method of claim 10, further comprising planarizing the second dielectric material with an upper surface of the protective film over the plurality of fins prior to recessing the second dielectric material.

15. The method of claim 14, wherein planarizing the second dielectric material with the upper surface of the protective film comprises a chemical-mechanical polishing terminating when the second dielectric material is co-planar with the upper surface of the protective film over the plurality of fins.

16. The method of claim 10, further comprising removing the protective film following recessing the second dielectric material to expose the upper fin portions of the plurality of fins.

17. The method of claim 1, wherein the dielectric material is an oxide material.

18. The method of claim 1, wherein uniformly recessing the dielectric material comprises reactive-ion etching the dielectric material.

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